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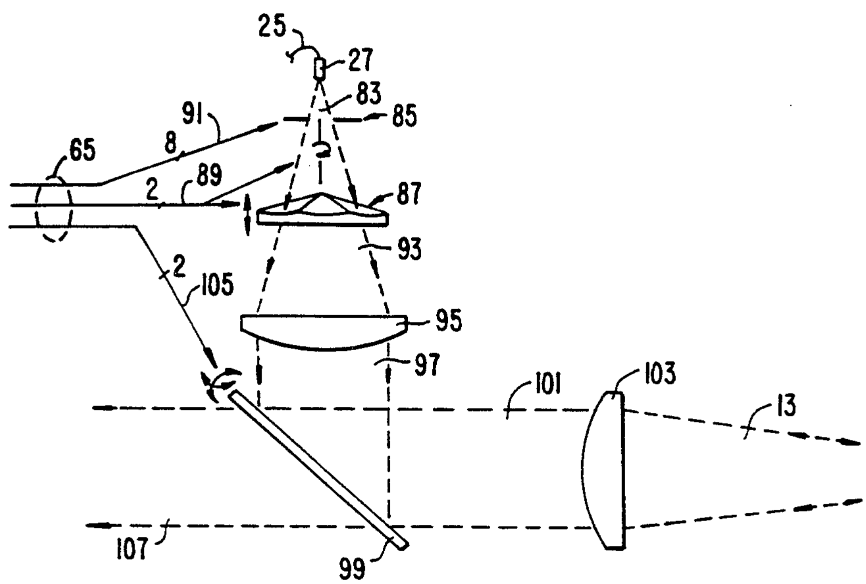

(57) Abstract

Primarily adapted for use in photo-thermal-keratoplasty procedures wherein a human eye is corrected for near-sightedness, farsightedness, astigmatism, and the like, by shrinking collagen within the cornea through controlled heating with infra-red radiation, an optical system is provided to controllably generate an infra-red radiation pattern. A moveable muti-faceted prism (87) is a primary optical element. Both the infra-red heating radiation and visible aiming radiation are delivered to the prism (87) by a multi-mode optical fiber (25). The optical elements are arranged to provide an attending physician with a clear view through the system of the eye being treated. Adjustment of the infra-red pattern is electrically controlled.

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METHOD AND APPARATUS FOR EXPOSING A HUMAN EYE TO A CONTROLLED PATTERN OF RADIATION SPOTS

BACKGROUND OF THE INVENTION

This invention relates generally to various methods of treating a human eye with focused electromagnetic radiation, and, more specifically, to an improved apparatus for controllably focusing one or more spots of electromagnetic radiation on a cornea.

Although there are many specific treatment procedures involving the necessity for directing a highly controlled beam of electromagnetic radiation to an eye, keratoplasty procedures are currently receiving a great deal of attention because of their ability to correct an eye for nearsightedness, farsightedness and/or astigmatism. In one surgical procedure, a radiation beam is used to cut controlled portions of the cornea by ablation of tissue in its path. A specific application of this is in the performance of radial keratotomy procedures without the necessity of using the knife to perform radial cuts in the cornea.

An alternative procedure, which avoids cutting the cornea, directs one or more focused beams of electromagnetic radiation within the infrared portion of the spectrum into the eye to thermally shrink collagen tissue within the cornea in order to cause permanent corrective changes in the cornea curvature. This later technique often termed photo-thermal-keratoplasty, is the subject of U.S. Patent No. 4,976,709, issued December 11, 1990 to Dr. Bruce J. Sand. The collagen

shrinkage technique promises to provide permanent changes to the optical characteristics of the human cornea with a higher degree of safety and patient comfort than is the case with techniques that involve physically cutting and removing portions of the cornea.

In order for an ophthalmologist or other attending physician to be able to efficiently perform corrective photo-thermal-keratoplasty procedures on a large number of patients with a high degree of accuracy and effectiveness, it is desired to provide an instrument that accurately directs the correct amount of infrared radiation into the patient's cornea with a pattern that is controllable by the physician with a high degree of accuracy. A basis for such an instrument is described in published European Patent Application No. 402,250, dated December 12, 1990, of Parel et al. The instrument there disclosed provides a controllable arc, circle, radial lines, or array of spots of infrared radiation across the cornea of a patient's eye. The Parel et al. system configuration is described as useful for any of several surgical and non-surgical procedures.

It is a primary object of the present invention to improve the type of instrument disclosed by Parel et al.

It is also an object of the present invention to provide such an instrument with a computer controlled operation.

It is another object of the present invention to provide a system, for exposing a cornea to a controlled pattern of radiation, that is efficiently manufacturable, useable, accurate, and effective.

It is a further object of the present invention to provide an improved method and system for projecting a controlled pattern of infrared radiation spots against the cornea of the eye in performance of a photo-thermal-keratoplasty procedure.

SUMMARY OF THE INVENTION

Accordingly, briefly and generally, many individual improvements have been made in the Parel et al. system which each contribute to reaching the aforementioned objects, both individually and in cooperation with one another. One aspect of the present invention involves a rearrangement of the optical system disclosed in the prior art discussed above for generating and directing an infrared pattern against a patient's cornea that is being treated. A small, substantial point source of a diverging beam of infrared radiation is directed against an optical element that shapes the beam into the desired pattern. The pattern is controllable by rotation and longitudinal movement of this optical element along an optical axis of the diverging beam. A mask is provided in the diverging beam either before the optical element or immediately after it in order to contribute to control of the intensity distribution of the beam across its pattern. The controlled beam is then collimated and focused onto a surface in space where a patient's eye is to be positioned. A dichroic mirror is positioned in the collimated portion of the beam in order to allow the physician to view the patent eye surface along the same path as the treatment beam takes.

This arrangement has several advantages. It is mechanically simpler and optical elements are removed from the patient in order to provide more room around the patient for the attending physician to work. The physician's view of the eye through the dichroic mirror is not degraded, as is often the case in such instruments, since the mirror is placed in a collimated portion of the beam rather than where the beam is diverging or converging. This arrangement also allows a positive, convex radiation pattern forming optical element to be utilized and yet have the radiation beam

strike the eye surface substantially perpendicularly. A substantial perpendicular incidence of the beam in the cornea of the eye provides the best results with whatever particular procedure is being performed, specifically with photo-thermal-keratoplasty procedures. A negative, concave optical element can be positioned most anywhere in the system and still result in the desired perpendicular incidence of the radiation beam against the eye but such negative optical elements are very difficult to manufacture with the required precision, if even possible. An instrument designed specifically for photo-thermal-keratoplasty procedures according to the present invention utilizes a positive, multi-faceted prismatic elements (polyprism) in order to divide the diverging radiation beam into a number of separate beams, one such beam from each face of the prism. Each of these beams is focused to a substantial point sized spot on the cornea of the patient's eye.

Since the infrared treatment radiation is not visible, it is desirable to direct electromagnetic radiation from a visible source coaxial with the treatment radiation so that the physician can visually adjust and position the pattern on the patient's cornea. According to another aspect of the present invention, separate sources of infrared and visible radiation are combined and transmitted by a multi-mode optical fiber to the remaining optics of the instrument. The combined infrared and visible radiation beams then emerge from the optical fiber as the diverging beam discussed above. This configuration has at least four distinct advantages. First, the separate infrared and visible radiation source beams are precisely coaxially aligned with each other, something that is not easy to otherwise accomplish. This alignment remains in tact even if individual optical elements within the system may become somewhat misaligned as a result of mechanical jarring or

the like. Secondly, the multi-mode optical fiber provides a scrambling or diffusion of each of the beams being passed through it so that the emerging diverging beam has a very uniform intensity distribution cross it. A third advantage resulting from use of the optical fiber is that its core diameter provides a control of how small the individual spots may be focused on the eye. As a forth advantage, the optical fiber provides an electrical isolation of the portion of the optical system adjacent the patient, and with which the physician directly works, from the radiation sources which generally utilize high voltages. Although not necessary for the procedures described herein, individual lasers are usually utilized to generate the infrared and visible beams.

According to another aspect of the present invention, a controllable mask structure is provided to work with a polyprism optical element that divides the beam having passed through the mask into a plurality of separate beams that form separate spots on the patient's eye. A separately adjustable shutter mechanism is provided for each portion of the diverging beam that strikes a separate face of the polyprism. Each of these shutters has an individually controlled rest open position so that the relative intensity of each beam resulting from the polyprism, and thus of each of the spots directed against the patient's eye, is controllable when the shutters are open. Generally, this is utilized to balance the intensity of the individual beams to compensate for the effects of dust, irregularities in other optical elements and the like, but it can also be used to intentionally provide different intensities of each of the beams and their focused spots. Each of the shutters may be completely closed or opened to this adjusted position in response to either manual or electrical actuation.

According to another aspect of the present invention, a slit lamp biomicroscope may be positioned between the instrument and the patient's eye in order to allow the attending physician to examine an interior of the patient's eye in the way that is accomplished with a biomicroscope when used alone. This combination is made possible because of the clear view that the attending physician has through the dichroic mirror of the instrument of the present invention and into the patient's eye. This eliminates the need for the attending physician to first examine the patient with a separate slit lamp microscope and then reposition the patient in front of the treatment system.

According to another aspect of the present invention, achromatic compensation is provided in a collimating lens system with sufficient correction so that it need not be also provided in the lens system that focuses the collimated beam onto the patient's eye. Because the treatment infrared radiation and the visible radiation beams are separated significantly in wavelength, wavelength dependent optical systems will treat them differently. Thus, the higher level of correction than usual which is necessary in this system is provided by only one of the optical elements in the system, the others at most providing the normal chromatic correction in the visible spectrum that ordinary lens systems provide.

Additional objects, advantages and features of the present invention will become apparent from the following description of a preferred embodiment thereof, which description should be taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is an overall system view of a treatment instrument that incorporates the various aspects of the present invention;

Figure 2 illustrates a pattern of radiation spots that is generated by the system of Figure 1;

Figure 3 shows the primary elements of an optical system of the instrument of Figure 1;

Figures 4A and 4B show top and side views, respectively, of a polyprism utilized as one of the elements of the optical system of Figure 3;

Figure 5 is a plan view of the primary elements of an adjustable shutter mask used in the optical system of Figure 3;

Figure 6 is a more comprehensive view of the mask of Figure 5 showing a preferred operable embodiment thereof; and

Figure 7 illustrates a preferred achromatic lens arrangement for use in the system of Figure 3.

DESCRIPTION OF A PREFERRED EMBODIMENT

Referring initially to Figure 1, an overall view of a system embodying the various aspects of the present invention is first described. An optical treatment instrument 11 is adapted to direct a controlled radiation pattern in a beam 13 onto a cornea of an eye 15 of a patient that is being treated. An attending ophthalmologist or other physician is indicated by a symbol 17 of another eye in a position looking through a binocular eye piece 19 to view the patient's eye 15 along a path coincident with the beam 13. Primary optics of the instrument 11 are included in orthogonally arranged housing portions 21 (substantially horizontal) and 23 (substantially vertical). A light input to the instrument 11 is provided by a single multi-mode optical fiber 25 that is attached by an

optical connector 27 near the top of the instrument. The instrument 11 is attached through a post 29 to a carriage 31 that is moveable back and forth along a fixed platform 33 in response to operation of a hand crank 35. A patient head restrict mechanism of a usual type is also provided, indicated to include a post 37 that is attached to the platform 33 and includes a chin rest 39 on which the patient rests the weight of his or her head and a forehead positioning bar 41 against which the forehead of the patient is urged. Thus, the patient's eye is held stationary while the optical instrument 11 is adjustable back and forth horizontally with respect to the eye. Also, the patient is maintained in an upright position during treatment since the cornea will generally be of a different shape if the patient is lying down. Optimal correction to the patient's eyesight is desired for the more usual upright position.

A source 43 of electromagnetic radiation for use in the instrument 11 includes, in this example, two lasers 45 and 47. The laser 45 generates a beam 49 of infrared treatment radiation, while the laser 47 generates a visible light beam 51. A mirror 53 and a dichroic mirror 55 combine both laser optic beams through an appropriate focusing lens 57 into an optical connector 59 to which the optical fiber 25 is attached. Thus, the output of each of the lasers 45 and 47 is directed along the fiber 25 to a connector 27 at its opposite end. The laser 45 should generate radiation having a wavelength within a range of substantially 1.8 to 2.55 microns for a photo-thermal-keratoplasty procedure. An example laser is of a solid-state type with lasing material having an yttrium-aluminum-garnet host and an activator that is a combination of thulium, holmium, and chromium (THC:YAG). The visible laser 47 can generate a beam in any convenient visible region,

such as the green 543 nanometer line of a helium-neon laser.

As a third major portion of the system of Figure 1, a computer system 61 controls the radiation source 43 over control lines 63 and controls the optical instrument 11 over control lines 65. Primary control exercised over the radiation source 43 is to independently control when the treatment laser 45 and the visible laser 47 are turned on and off. Additionally, the treatment laser 45 is generally pulsed in a very precise manner during treatment. The primary control exercised over the instrument 11 is the physical positioning of various optical elements and shutters, as described below. The computer system 61 is connected to some input-output device or devices 67 in order to provide an interface with the attending physician. Such a device will generally include controlling electrical push button switches, CRT monitor and status lights.

An additional piece of equipment attached to the carriage 31 is a narrow slit eye illumination system 69 of a standard available type. Such a system includes a prism 71, at the top of a column, through which the output beam 13 from the instrument 11 is directed. The illuminating source 69, when energized, directs a slit of light against the patient's eye 15, thereby allowing the attending physician to examine the interior or surface of the patient's eye by looking through the binoculars 19 and instrument 11. By including the slit lamp as part of the instrument 11, the attending physician can both examine and treat the patient with a single instrument, thereby not having to reposition the patient between two different pieces of equipment.

Referring to Figure 2, a specific example of the radiation pattern provided in the output beam 13 of the instrument 11 is shown. A circle 71 defines a surface upon which the radiation beam 13 is focused,

that surface being coincident with a patient's cornea. In this example, the beam 13 focuses the radiation into 8 spots 73-80 on that surface, equally spaced around a circle 81 having a radius "r" from a center of the surface 71 which is coincident with the center of the patient's cornea. Both the treatment infrared radiation and the visible radiation are focused by the instrument 11 into the same spots 73-80. Thus, prior to directing the infrared treatment radiation toward the patient's eye, the attending physician can view through the binoculars 19 the exact spots on the patient's eye 15 where the treatment radiation will be incident.

Referring to Figure 3, the primary optical elements of the instrument 11 and their operation will be explained. A diverging radiation beam 83 emerges from an end of the optical fiber 25 through the connector 27. The degree of divergence is controlled by the numerical aperture of the particular optical fiber used. A single core, multi-mode optical fiber is chosen to have a core diameter much greater than the wavelength of the radiation being passed through it. This assures the mixing that is desired in order that the intensity distribution across the beam 83 is substantially uniform. However, the core diameter does define the smallest size of the spot 73-80 (Figure 2) that will be possible to generate by the instrument 11, so should not be made excessively large.

In the diverging radiation beam 87, a mask and shutter structure 85 is positioned (described in detail below with respect to Figures 5 and 6) and a polyprism 87 (described in detail with respect to Figures 4A and 4B.) In this example, the polyprism 87 has 8 separate faces, each face deriving from the diverging beam 83 a separate beam that is later focused into one of the spots 73-80. An appropriate motor source is provided to both rotate the polyprism 87 and move it axially along

the length of the radiation beam 83, in response to control signals in lines 89 which are part of the control lines 65 (Figure 1) from the controlling computer system 61. Rotation of the polyprism 87 about the optical axis causes the spots 73-80 (Figure 2) to rotate. The shutter structure 85 is rotated along with the polyprism 87 but is not moved axially. Movement of the polyprism along the length of the optical axis causes the radius "r" to change.

A preferred shutter structure 85 provides a separate shutter element for each portion of the cross section of the beam 83 that strikes a separate face of the polyprism 87. Each of these shutters is independently controlled between opened and closed positions by signals in control lines 91 which are part of the control signal 65 (Figure 1) from the computer system. The structure and operation of an example shutter structure 85 is given below.

After the diverging beam 83 passes through the polyprism 87, a resulting group of 8 separate beams 93 is collimated by an appropriate optical assembly indicated by a spherical lens element 95. A collimated beam 97, made up of these individual 8 beams, is reflected from a dichroic mirror 99 to direct the composite collimated beam 101 to a focusing optical system indicated by a spherical lens 103. The lens 103 focuses the beams in the form of the output beam 13 into each of the individual spots 73-80 (Figure 2).

The dichroic mirror 99, positioned between the lenses 95 and 103, also allows visible radiation reflected from the patient's eye to pass through in the form of a beam 107. It is this beam 101 that is viewed through the binoculars 19 (Figure 1) by the attending physician in order to observe the patient's eye. The mirror element 99 is caused to be adjustable a small amount by two motor sources, one for each of the x and

y directions, which are controlled over lines 105 that are part of the control lines 65 (Figure 1) from the computer 61. This adjustment moves the entire pattern of dots 73-80 around on the patient's eye for proper positioning.

The optical arrangement shown in Figure 3 provides many of the system advantages that are discussed above. By positioning the dichroic mirror 99 in a collimated portion 97 and 101 of the radiation path, its presence does not severely distort the visible light in the beam 107 that is desired for the attending physician to view. Steps normally taken to minimize that distortion when such an element is positioned in a diverging or converging beam is unnecessary. The physician maintains a clear view through the element 99, the selection of which is not constrained by the desire for such a clear view. It will also be noted that by positioning the polyprism in the diverging beam 83 rather than in the converging beam 13, there is more space permitted between the instrument 11 and the patient's eye 15 which makes it much easier to perform the desired treatment.

A structure of the polyprism 87 is shown in an expanded view in Figures 4A and 4B. Figure 4A is a plan view of the polyprism 87, as viewed in the system of Figure 3 from the shutter assembly 85. The view of Figure 4B is an expanded side view as given in Figure 3. This specific polyprism being described includes eight adjacent planar surfaces 111-118, each of which forms the diverging beam 83 (Figure 3) into a separate beam that results in a corresponding one of the radiation spots 73-80 (Figure 2). Of course, a different number of such planar faces other than 8 may be employed in order to generate a different number of spots on the patient's eye. Further, the surfaces need not be planar if a particular spot shape is desired to be controlled.

Also, although the structure of the polyprism 87 is made to be symmetrical, in order that the resulting spots 73-80 are evenly spaced around a circle, these spaces may be arranged non-symmetrically if it is desired to generate a non-circular or non-symmetrical pattern of radiation spots on the patient's eye.

For most applications of the system of Figure 1, particularly in photo-thermal-keratoplasty procedures, it is desirable that each of the individual beams resulting in the spots 73-80 (Figure 2) strikes the patient's eye substantially perpendicular with its curved surface. This is accomplished with a positive, convex polyprism 87. If a polyprism were to be positioned in the converging beam 13 at the exit of the instrument 11, the same perpendicular incidence of the individual beams formed by the polyprism would result if that polyprism were a negative, concave type. This is a serious disadvantage since the formation of a multiple faces of the prism to extend inward with precision is an extremely difficult manufacturing task. The making of a positive concave polyprism 87 is much easier. The positioning of the polyprism in the diverging beam 83 (Figure 3) has, therefore, the advantage that it may be of a positive convex type but still provide the desired perpendicular incidence of its beams on the patient's eye.

Referring to Figure 5, a plan view of a preferred shutter assembly 85 (Figure 3) is given in order to explain in general terms its operation, while a more detailed mechanical implementation is shown in the partially broken away plan view of Figure 6. A solid, opaque mask 121 is a central element. This mask is provided with eight wedge shaped apertures 122-129. These apertures are positioned within a circle that is illuminated by a substantially uniform intensity cross-sectional portion of the diverging beam (Figure 3).

Each of the apertures 122-129 is associated with a respective one of the faces 111-118 of the polyprism 87. Indeed, the wedge shape of each of the apertures 122-129 is chosen to approximately match the shape of the polyprism faces (Figure 4A).

The amount of light from the diverging beam 83 that is allowed to pass through each of the apertures 122-129 is separately controlled by individually actuatable shutters 131-138. Each of these shutters is formed at its innermost end into a wedge shape that matches that of its associated one of the apertures 122-129. Each of these shutters may be positioned with its wedge shaped end completely removed from its associated aperture, as is the case with the shutter 135 being totally removed from the aperture 126, at one extreme, to the case where the shutter completely covers its associated aperture to completely block the radiation from passing through it, as shown by the shutter 133 over the aperture 124. Other shutters are illustrated in Figure 5 to block a portion of their respective apertures. Thus, full control of the intensity of the portion of the beam 83 (Figure 3) that is formed into each of the spots 73-80 (Figure 2) is individually controllable. Usually, it is desired to equalize the intensities of the spots 73-80 but some other relationship between their intensities may be easily obtained by the shutter mechanism of Figures 5 and 6, if desired.

Referring primarily to Figure 6, additional details of the structure of the shutter mechanism 85 will be explained. The mask plate 121, shown in an enlarged form of Figure 5 is sandwiched between a base housing member 141 and a cover member 143, both having matching circular shapes. The cover member 143 has a circular opening 145 that exposes a center portion of the mask 121. Similarly, the bottom housing member 141

includes a circular opening 147 formed by a ring 148 that exposes the mask 121 from its opposite side. Thus, the light beam being controlled passes through the center housing openings 145 and 147 when passing thorough the wedge shaped apertures 122-129 of the mask 121.

Each of the shutters 131-138 is operated by the same type of mechanism, various parts of that mechanism being shown in different degrees of cutaway views of four such shutters. Each of the shutters is carried by a block, the shutter 133 by a block 149 and the shutter 134 by a block 151. A block 153, shown with its shutter removed, can be seen to be reciprocal within a radially aligned slot 155 within the base housing member 141. A spring 157 within a bore at one end of the block 153 urges a pin 159 against the ring 148. This structure tends to urge the block 153, and thus its attached shutter blade, radially outward away from the opening 147. An adjustment screw 161 provides an adjustable stop that defines an extreme position of the block 153 when the shutter is opened. The screw 161 is threaded into the base member 141 and is adjustable by hand from a circumference of the base member 141. Thus, the amount that each of the shutters 131-138 extends into the respective apertures 122-129 of the mask 121, when in an opened position, is defined by the adjustment of these individual screw stops, such as the screw 161.

A further mechanism is provided for individually moving each of the shutters 131-138 from its open position, as defined by these screws, to a completely closed position. The shutter 133 is shown in Figure 6 to be in that closed position, its block 149 being urged by a pin 163 in a radially inward direction against the force of its internal spring. A counterpart pin 165, which operates the adjacent shutter carrying block 151, is shown withdrawn from its block 151 in

order to allow the block to be urged by its internal spring against its associated screw stop. This pin is driven in a manner to have two stable positions, the pin 163 to be in one of them, wherein its associated shutter is closed as the block 149 is urged against the ring 148, and the pin 165 shown to be in the other of the two stable positions, wherein its associated shutter is fully opened an amount allowed by its associated screw stop. This pin, as best shown for a pin 167 associated with an adjacent shutter mechanism, is eccentrically carried by a rotating element 169 that is journaled within a matching aperture of the cover plate 143.

The rotating member 169 has a shaft 171 at its center of rotation extend upward through the cover plate 143, as indicated by shafts 173-176 for four of the adjacent shutter/block mechanisms which lie below the cover plate 143 of the figure 6 view. The rotating member 169 is provided with two stable positions 180 degrees apart from each other. In a version of the instrument requiring hand manipulation to individually open and close the shutters, a leaf spring 177 is used to provide the two stable rotatable positions. The spring 177 is attached to the cover plate 143 and parallel opposing sides on a portion of the rotating member 169 which engages the spring 177. The two stable positions are indicated respectively by positions of the pins 163 and 165, being shown in Figure 6 for two adjacent shutter mechanisms. In a motorized version of the instrument, the spring 177 can be omitted since the driving motors will generally provide the two stable stop positions of the rotating member 169.

Each of these rotating members is individually controlled so that each of the shutters may be independently opened and closed. It is preferable to drive each of these operating members by an electric motor source of some type, motors 181-184 being shown in

Figure 6 for four of the shutter mechanisms. Four additional motor sources are provided to individually drive the other four shutter mechanisms which are shown in various stages of cutaway and disassembled views. The motor sources are driven by control signals in lines 91 which are provided as part of the lines 65 (Figure 1) from the computer control system.

Thus, it can be seen that a total of 12 motors are controllable by the system computer 61 to adjust which of the spots 73-80 (Figure 2) will be directed to the patient's eye and the pattern in which those spots will appear.

It is common in any optical system utilizing refractive optical elements to compensate for the different effect such elements have on optical radiation of different wavelengths. A focusing lens system, for example, generally contains additional elements to assure that all visible light wavelengths are focused in the same manner. In the case of the instrument being described, such a correction extends beyond wavelengths within the visible spectrum since the treatment laser 45 (Figure 1) emits a treatment radiation beam outside of that range, within a near-visible portion of the electromagnetic radiation spectrum. The optical system of Figure 3 must then be provided with appropriate correction so that this treatment radiation and that from the visible laser 47 is focused in the same manner. Particularly, the visible and treatment radiation must form coincident spots 73-81 (Figure 2) on the patient's eye so that the attending physician can have a precise view of exactly where the treatment radiation will be directed. The visible radiation provides this view.

Each of the refractive optical elements, 87, 95 and 103 can be provided with such chromatic correction but it has been found preferable instead to replace the simple lens system 95 with a corrective lens

assembly 95' of Figure 7. The focusing lens 103 may be provided with normal chromatic correction for visible wavelengths but is not corrected for the extraordinary difference of the wavelengths between the two light sources 45 and 47. This correction is provided for the system as a whole by the lens assembly of Figure 7. In this example, a high dispersion (n=1.8) lens 191 has two concave surfaces. Single convex lens elements 193 and 195 are also provided and are chosen to have a low dispersion (n=1.4). The lenses 193 and 195 are preferably made from magnesium fluoride (MgF_2) material.

Although the various aspects have been described with respect to preferred embodiments thereof, it will be understood that the invention is entitled to protection within the full sccpe of the appended claims.

IT IS CLAIMED:

1. A radiation exposure system adapted for use with the human eye, comprising:

a source of infra-red electromagnetic radiation,

a source of visible electromagnetic radiation,

a length of a multi-mode optical fiber having first and second ends,

means receiving radiation from each of the infra-red and visible sources for coupling that radiation into said first optical fiber end, thereby to provide superimposed infra-red and visible radiation exiting said second optical fiber end,

a first optical means receiving superimposed radiation from the second fiber end for generating a plurality of spatially separate beams that each include substantially coaxially aligned infra-red and visible components,

a second optical means receiving said beams for collimating said beams, and

a third optical means receiving said collimated beams for focusing each of them to a substantial point at a focal surface, whereby a human eye may be positioned coincident with said surface to be exposed to said radiation points.

2. The system according to claim 1 which additionally comprises:

a fourth optical means positioned between said second and third optical means in a path of said collimated beams for reflecting said beams from one side thereof toward said third optical means while allowing visible radiation to pass therethrough, and

an optical viewer positioned to provide a vision path through said third and fourth optical means, thereby to allow viewing of the focal surface.

3. The system according to claim 2 which additionally comprises means positioned between the third optical means and said focal surface for illuminating said focal surface with a slit of light, whereby an interior structure of a human eye positioned at said focal surface may be viewed through said optical viewer.

4. The system according to claim 2 wherein the first, second, third and fourth optical means are arranged so that the vision path from the optical viewer through the third and fourth optical means to the focal surface is substantially horizontal.

5. The system according to claim 2 which additionally comprises means responsive to control electrical signals for adjusting a position of said fourth optical means with respect to said second and third optical means, thereby to provide for controlling positioning of the focused radiation points on the focal surface.

6. The system according to either of claims 1 or 2 which additionally comprises means positioned between the optical fiber second end and the first optical means for providing separate attenuation control of portions across the radiation exiting the second fiber end that correspond to the separate beams formed by the first optical means, whereby the intensity of the separate beams is individually controllable.

7. The system according to either of claims 1 or 2 which additionally comprises:

means positioned between the optical fiber second end and the first optical means for providing separate attenuation control of portions across the radiation exiting the second fiber end that correspond to the separate beams formed by the first optical means, and

means connected to the attenuation control means and responsive to control electrical signals for individually controlling the intensity of the separate beams, whereby the intensities of the beams and their resulting radiation points focused on the focal surface are individually controllable by the control electrical signals.

8. The system according to either of claims 1 or 2 which additionally comprises a mask positioned in a path of the radiation exiting said second optical fiber end, said mask including a plurality of shutters positioned in a manner that one shutter is associated with each of said plurality of spatially separate beams, each of said shutters being slidable in a radial path across a cross-section of the radiation between an outward open position and an inward closed position, and means provided with each of said shutters for adjustably defining an extent of attenuation provided thereby when said shutter is in its said open position.

9. The system according to either of claims 1 or 2 wherein the radiation exiting the second optical fiber end is diverging when received by said first optical means.

10. The system according to either of claims 1 or 2 wherein said first optical means includes a multi-faceted prism.

11. The system according to either of claims 1 or 2 wherein said first optical means includes a convex multi-faceted prism.

12. The system according to either of claims 1 or 2 wherein said first optical means includes a multi-faceted prism, and which additionally comprises means responsive to control electrical signals for independently rotating said prism and moving said prism in a direction between the second fiber end and the first optical means, thereby to be able to control the spacing and rotatable position of the focused points on the focal surface in response to the control electrical signals.

13. The system according to either of claims 1 or 2 wherein said third optical means contains substantially no chromatic correction, and further wherein said second optical means includes an excessive visible wavelength chromatic correction so that said infra-red and visible radiation within the beams focused by the third optical means onto the focal surface are coaxially aligned, whereby their focal points are superimposed.

14. The system according to either of claims 1 or 2 wherein the infra-red electromagnetic radiation of the infra-red radiation source has a wavelength that lies substantially within a range of from 1.8 microns to 2.55 microns.

15. The system according to either of claims 1 or 2 wherein each of the infra-red and visible radiation sources includes a laser.

16. The system according to either of claims 1 or 2 wherein each of the infra-red and visible radiation sources are independently controllable between on and off conditions.

17. A radiation exposure system adapted for use with the human eye, comprising:

a source of infra-red electromagnetic radiation,

a source of visible electromagnetic radiation,

a first optical means receiving superimposed radiation from each of said infra-red and visible radiation sources for generating a plurality of spatially separate beams of said radiation,

a second optical means receiving said beams for collimating said beams,

a third optical means receiving said collimated beams for focusing each of said beams to a spot at a focal surface, whereby a human eye may be positioned coincident with said surface to be exposed to said radiation spots,

a fourth optical means positioned between said second and third optical means in a path of said collimated beams for reflecting said beams from one side thereof toward said third optical means while allowing visible radiation to pass therethrough, and

an optical viewer positioned to provide a vision path through said third and fourth optical means, thereby to allow viewing of the focal surface.

18. The system according to claim 17 which additionally comprises means positioned between the

third optical means and said focal surface for illuminating said focal surface with a slit of light, whereby an interior structure of a human eye positioned at said focal surface may be viewed through said optical viewer.

19. The system according to claim 17 wherein said first optical means includes a convex multi-faceted prism.

20. The system according to claim 17 which additionally comprises a mask positioned in a radiation path prior to said second optical means, said mask including a plurality of shutters positioned in a manner that one shutter is associated with each of said plurality of spatially separate beams, each of said shutters being slidable in a radial path across a cross-section of the radiation between an outward open position and an inward closed position, and means provided with each of said shutters for adjustably defining an extent of attenuation provided thereby when said shutter is in its said open position.

21. The system according to claim 19 which additionally comprises a mask positioned in a radiation path prior to said prism, said mask including a plurality of shutters positioned in a manner that one shutter is associated with each of said plurality of spatially separate beams, each of said shutters being slidable in a radial path across a cross-section of the radiation between an outward open position and an inward closed position, and means provided with each of said shutters for adjustably defining an extent of attenuation provided thereby when said shutter is in its said open position.

22. The system according to either of claims 20 or 21 which additionally comprises a plurality of individually controllable motor sources, separate of said motor sources being operably connected to operate each of said plurality of mask shutters and position each of said first and fourth optical means.

23. An optical mask, comprising:

an opaque structure having at least one aperture through which a beam of radiation having an optical center may pass,

a plurality shutters formed into a wedge shape at one end thereof,

means associated with each of said plurality of shutters for guiding movement of their wedge shaped end along a unique radial path with respect to said optical center, said guiding means including a resilient element normally biasing said shutter outward away from said optical center against a stop, and

means for individually moving said shutters against their said resilient elements across said aperture substantially to said optical center.

24. The optical mask of claim 23 wherein said optical stops are individually adjustable, whereby the biased positions of said shutters are individually controllable.

25. The optical mask of claim 23 wherein said shutters moving means includes associated with each of said shutters an eccentric pin attached to a rotating member having first and second stable rotatable positions and oriented to cause the pin to urge its associated shutter guiding means inward to said optical center when in said first stable position and to

disengage from said shutter guiding means when in said second stable position.

26. The optical mask of claim 25 wherein said shutters moving means additionally includes an individually controllable motor means associated with each of the rotating members and responsive to an electric signal for causing said rotating member to rotate between said first and second stable positions.

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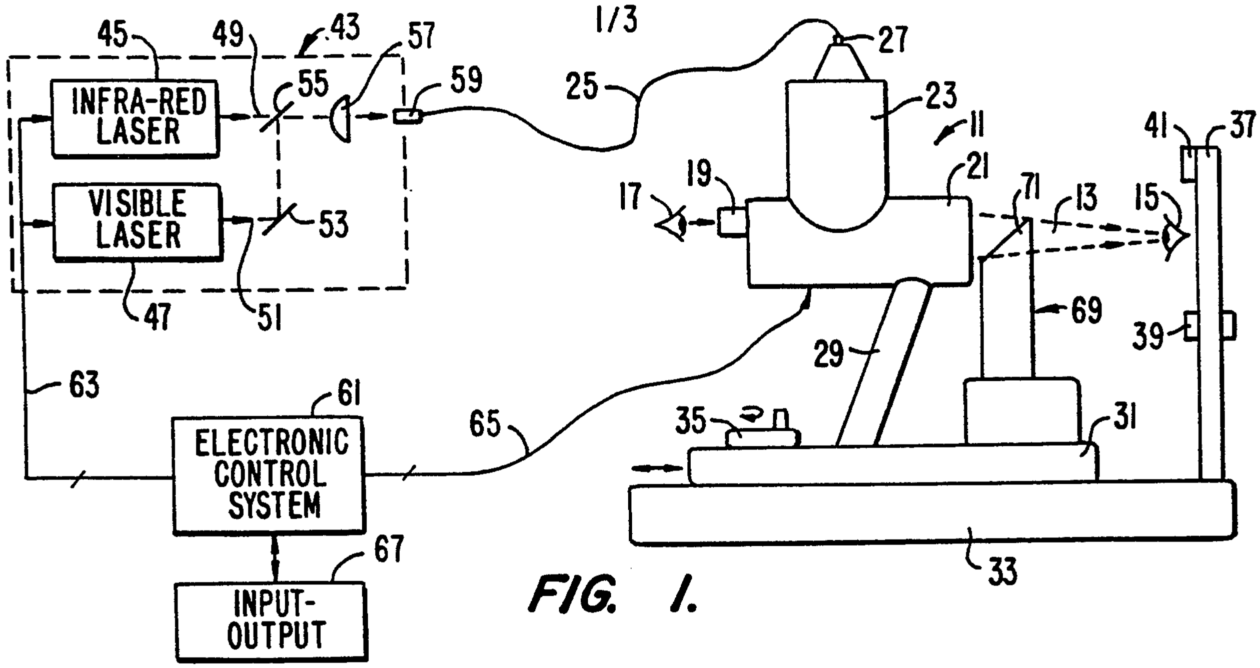

FIG. 1.

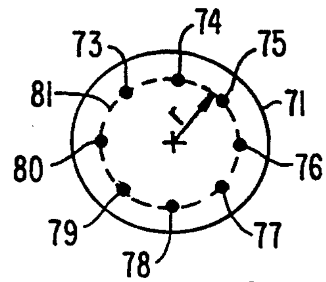

FIG. 2.

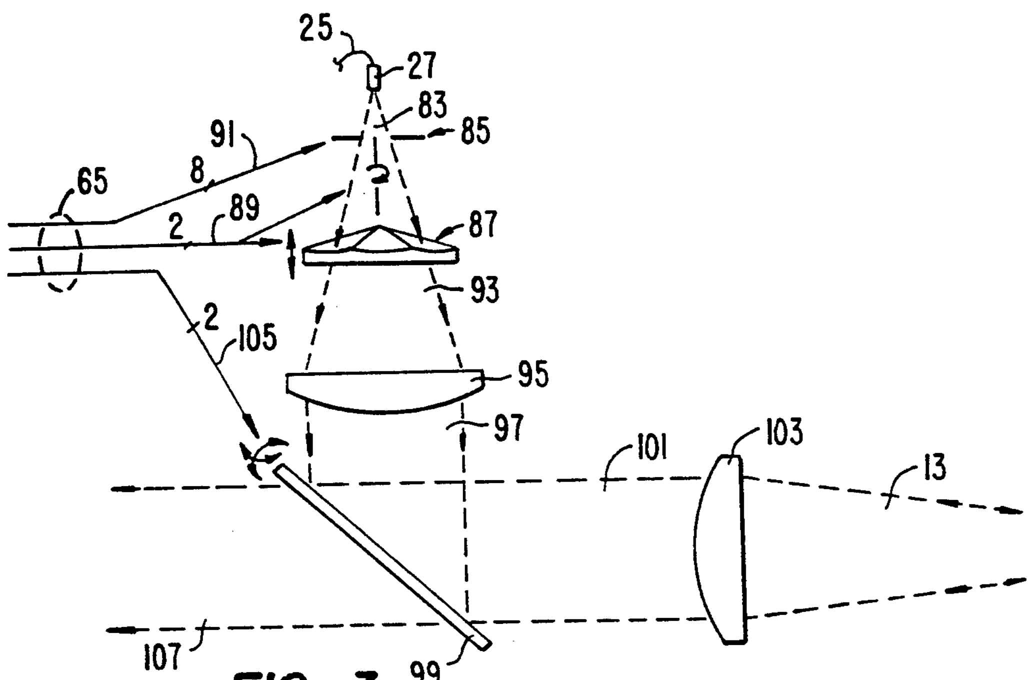

FIG. 3.

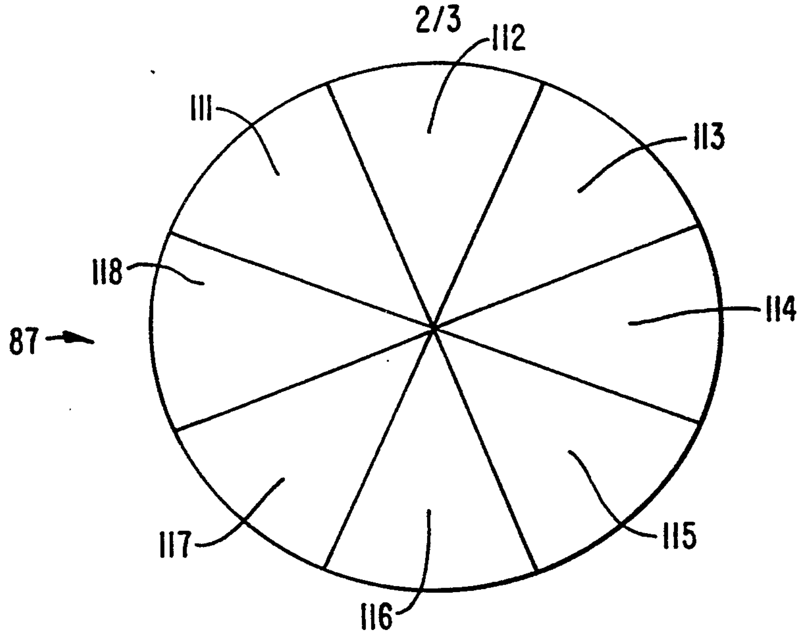

FIG. 4A.

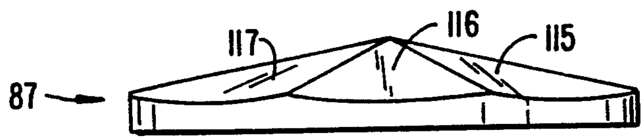

FIG. 4B.

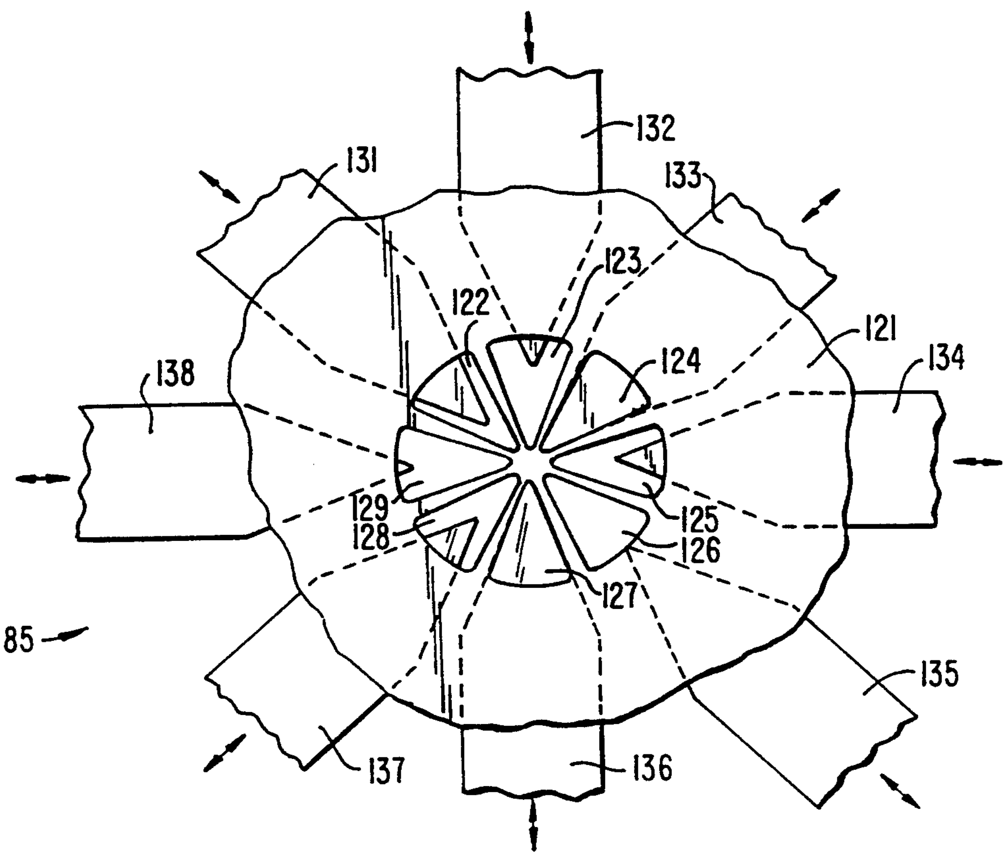

FIG. 5.

SUBSTITUTE SHEET

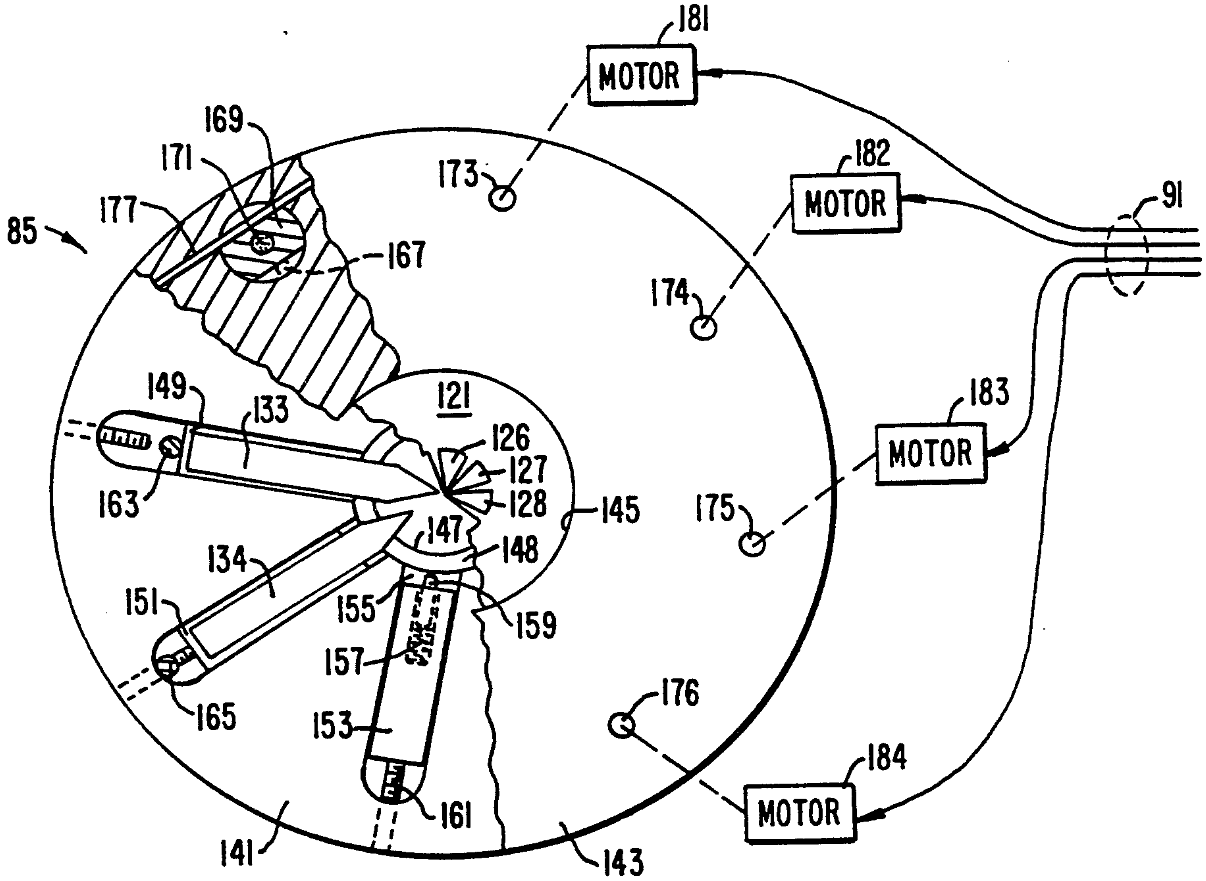
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FIG. 6.

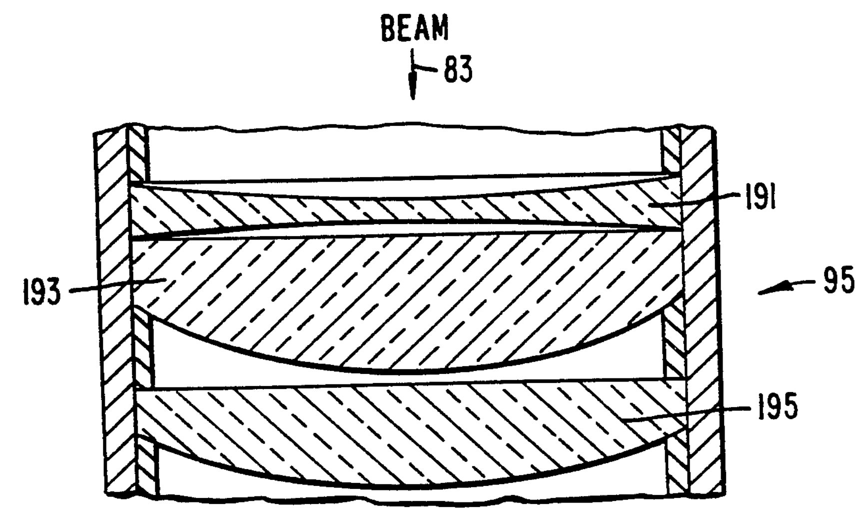
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FIG. 7.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 93/06965

A. CLASSIFICATION OF SUBJECT MATTER
IPC 5 A61F9/00 B23K26/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
IPC 5 A61F B23K A61B G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO,A,89 07920 (RODENSTOCK INSTRUMENTS) 8 September 1989	1-3, 9-11, 15-19
Y	see page 6, line 25 - page 9, line 18; claim 1; figures 1,2 ---	4-8,12, 14,20-22
A	WO,A,90 11054 (CANDELA LASER CORPORATION & MASSACHUSETTS GENERAL HOSPITAL) 4 October 1990 see abstract ---	2
Y	FR,A,2 635 972 (FIRMA CARL ZEISS) 9 March 1990 see claims; figure ---	4
Y	WO,A,87 01819 (RODENSTOCK INSTRUMENTE) 26 March 1987 see abstract ---	5

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"&" document member of the same patent family

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Date of the actual completion of the international search	Date of mailing of the international search report
18 November 1993	02. 12. 93

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+ 31-70) 340-3016	WOLF, C

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP,A,0 402 250 (UNIVERSITY OF MIAMI) 12 December 1990 cited in the application	6-8,12, 14,20-26
A	see the whole document cited in the application	1,2,4, 15,17,19
A	US,A,3 348 547 (A.J. KAVANAGH ET AL.) 24 October 1967 see column 12, line 42 - line 59; figure 7	13
A	US,A,4 669 839 (F. MUCHEL) 2 June 1987 see the whole document	13
Y	US,A,4 648 400 (R.T. SCHNEIDER ET AL.) 10 March 1987 see column 7, line 52 - column 8, line 50; figures 6-8	23-26
Y	EP,A,0 143 185 (FIRMA CARL ZEISS) 5 June 1985 see page 6, line 10 - line 25; figures 4,5	25,26
A	PATENT ABSTRACTS OF JAPAN vol. 7, no. 254 (M-255)(1399) 11 November 1983 & JP,A,58 138 588 (HITACHI SEISAKUSHO) 17 August 1983 see abstract see the whole document	23,24,26
A	WO,A,87 07829 (RODENSTOCK INSTRUMENTE) 30 December 1987 see the whole document	1-3,6-11
A	DD,A,263 447 (VEB CARL ZEISS) 4 January 1989 see claims 1,2; figures 1,1A	1,9-11, 19
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Information on patent family members

International Application No
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